ESTAINIUM Association

Time to act - Insights from the ESTAINIUM working groups.

April 2023

(Revision 2)

Management Summary

ESTAINIUM Association – cross-company collaboration for meeting the challenges of product related decarbonization.

The idea of ESTAINIUM as an open and independent association is to establish an ecosystem to meet present and future challenges of product related decarbonization. The ESTAINIUM members represent diverse roles in a future circular carbon economy: there are representatives from industry and research, verification organisations, carbon sink operators and software providers. ESTAINIUM's vision is to establish a path from carbon emission to carbon sink along multistage, complex production networks. This creates a direct link between economic activities, climate-damaging impacts as well as compensation measures. The focus is on calculating, exchanging, reducing, and offsetting carbon footprints along the supply chain through decentralized trust technology and self-sovereign data management.

Even though various norms and standards provide guidance for product carbon footprint (PCF) accounting, subjective interpretation is still required. Resulting consistency limitations can be tackled by strong alignment on methodology, PCF data models, high data quality and streamlined assurance criteria. Combined with a secure and trustworthy PCF sharing infrastructure and technology, reliable and high-quality data can be shared throughout the ecosystem without disclosing sensitive information. A strong focus on primary data instead of industry average values allows making even better business decisions as well as recognizable improvement. For carbon offsetting, criteria are defined to support the selection and comparison of carbon dioxide removal projects. This is indispensable for focusing on high quality removal projects with an assurance of avoided double accounting. All these topics are focused by the ESTAINIUM working groups to meet the association's vision:

The first working group is selecting and developing the basic technical infrastructure which is needed for the exchange of product related footprints. After identifying the requirements of all stakeholders, different technologies were analysed. They demonstrate that the preferred solution, the decentralized sharing approach by the Trusted Supply Chain Exchange (TSX) via verifiable credentials, can be used for sharing information across supply chain participants while fulfilling requirements on transparency, confidentiality, and data control.

The second working group is focused on simplifying the navigation in the increasingly complex landscape of PCF standards, norms, and sector or product specific guidance. It creates transparency about differences, facilitate alignment or at least standardizes translation between standards where possible. Major activities are the alignment of the required PCF data exchange models, the identification of suitable assurance schemes allowing a scaled-up verification practice as well as the development of guidance and best practices for members approaching PCF topics. The knowledge hub is currently under development and will be accessible to all members to provide tools as well as shortcuts to manage the PCF journey.

The third working group is developing guidelines to integrate high quality carbon removal projects in accounting mechanisms and product lifecycle management. The members analysed today's carbon dioxide removal solutions and the possibility of investing in such removal projects. For transparency and comparability, the group is working on a quality index for carbon removals. Several pilot projects provide opportunities for testing the linkage of emissions with carbon sinks and generate insights as well as best practices. Active discussions with politics support a regulatory framework which incentivises high-quality projects.

What ESTAINIUM have reached so far was only possible due to the company collaboration with a high commitment to decarbonize products and contribute to a better and sustainable tomorrow.

What is the idea of ESTAINIUM?

ESTAINIUM was founded in 2022 to establish a direct link between economic activity and its climate-damaging impacts. Our focus is on calculating, exchanging, reducing, and offsetting carbon footprints along the entire supply chain through decentralized trust technology and self-sovereign data management. This solution is characterized by lowering costs for operating infrastructure, maintaining data sovereignty of all participants, and enabling a fast scale-up. The ESTAINIUM members (see all on estainium.eco) represent diverse roles in the future ecosystem of a circular carbon economy: there are representatives from industry and research, certifying organisations, carbon sink operators and software providers. This unique constellation enables us to develop practical solutions to identify and overcome current and future challenges – for all stakeholders. In addition to the work across three technical working groups illustrated in text below, common use case studies and pilot projects are defined to learn and share the experience with the association's members. All activities drive towards the association's vision[1], which maps the path from carbon emission to carbon sink along multi-stage, complex production networks:

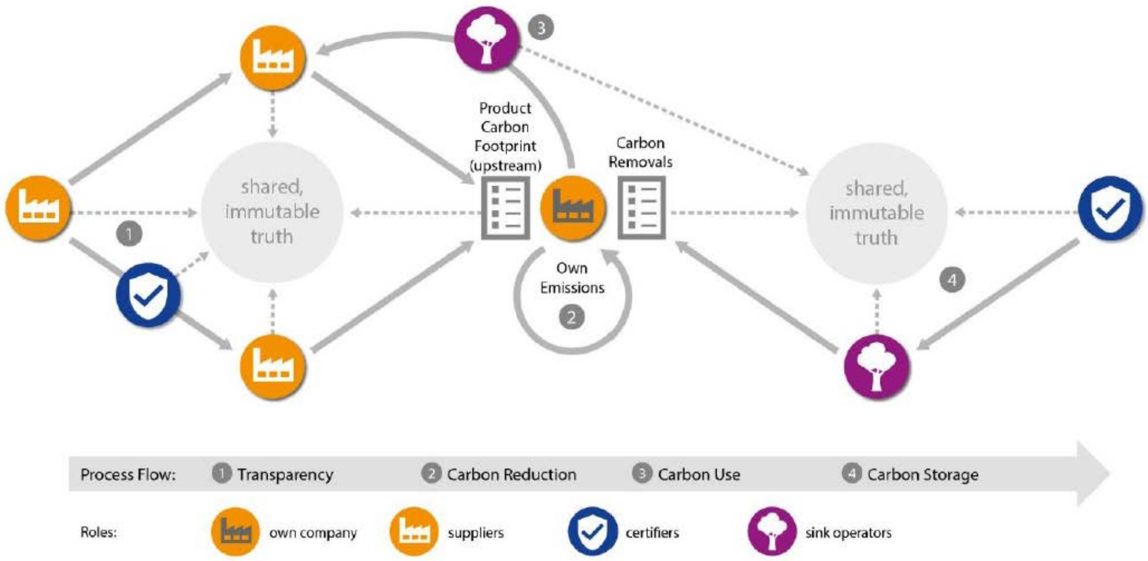

Figure 1 – Holistic Emission-to-Sink Approach to Decarbonize the Industrial Supply Chain.

As shown in the picture above, the ideal emission-to-sink process starts with creating transparency. An independent, trustworthy third party should check and verify the values provided. Data exchange along the value chain takes place based on a decentralized approach using common data formats and methods, considering requirements such as data protection and security. In the second step, the determined Product Carbon Footprint (PCF) must be reduced as far as possible. This can be done both by taking measures to reduce emissions in one's own production environment and by engaging upstream suppliers to reduce their emissions. Only when it is no longer possible to implement

[1] Read more in the mission statement

measures to reduce the PCF, the remaining emissions should be compensated by investing in CCUS projects. For this purpose, it currently is recommended to give preference to projects that remove CO_2 from the atmosphere and transform it into products that are as durable as possible (e.g., construction materials), as this enables the decarbonization of other value chains. In the fourth and final step, unavoidable emissions can be compensated by investing in long-term stable carbon reservoirs (e.g., deep sea or geological injection). In both the third and fourth step, it is essential that the carbon sinks are audited and verified by independent, trustworthy third-party institutions and that the information about which product is linked to which sink is stored in a safe and trustworthy environment. To achieve this vision, several technical challenges still need to be solved – ESTAINIUM wants to address these with recommendations from our three technical working groups presented in this publication. The ESTAINIUM association is part of the World Economic Forum initiative „Industry Net Zero Accelerator" and is a neutral platform to accelerate solutions for getting to net zero. The first publications have been released with the title "The "No-Excuse" Framework to Accelerate the Path to Net-Zero Manufacturing and Value Chains" in collaboration with Capgemini, University of Cambridge, Rockwell Automation, Siemens and ESTAINIUM. Furthermore, ESTAINIUM contributes to the initiative in addressing the Scope 3 challenge.

What are the challenges of today's product-related environmental accounting mechanisms?

Decarbonization of products refers to decreasing greenhouse gas emissions (predominantly CO_2) during production and delivery. Product emissions can only be decreased when managed in form of an aggregation of effective emissions throughout all production stages, and over all components and materials of a product. Such aggregation is referred to as a product carbon footprint and it can be analysed according to product life cycle stages as defined by the GHG Protocol (Product Standard) by WBCSD, an organization that provides standards, guidance, tools and training for business and government to measure and manage climate warming emissions:

- Reducing the direct greenhouse emissions caused by the company's operations (e.g. measured CO_2 emissions from fuel combustion),
- Reducing indirect emissions from the generation of purchased energy (e.g. electricity, steam or heating)
- Reducing indirect emissions caused by suppliers in the upstream value chain (e.g. components or auxiliary materials)
- By carbon offsetting (e.g., connecting carbon sink providers with manufacturers). This last option should only be considered after other decarbonization efforts are exhausted.

Various norms and standards provide guidance for PCF accounting. The basis are life cycle assessment (LCA) standards such as ISO 14044[2]. With carbon emissions being a single score impact

[2] M. Finkbeiner, et al. "The new international standards for life cycle assessment: ISO 14040 and ISO 14044." The international journal of life cycle assessment 11.2 (2006): 80-85.

category from a LCA, more GHG-specific norms such as the ISO 14067[3] or documents such as the GHG-Protocol Product[4] were defined. They partly deviate from each other due to their broad applicability in certain areas and still leave room for interpretation. Hence, for comparability reasons, individual industries defined Product Category Rules (PCRs) or even Product Specific Rules (PSRs) and sub specifications. They intend to provide a high comparability of LCA results for PCFs within homogeneous product groups.

All these initiatives assume, however, a conventional assessment of PCFs, with one practitioner modelling the entire value chain, including the process steps outside the practitioner's foreground system. To estimate activities that are not controlled by the assessing entity, the practitioner relies on assumptions reflecting industrial averages from secondary databases. The use of averages limits the comparability of different suppliers once the product design is locked. In the decarbonization use case, this means that the environmental implication of a procurement decision is limited to simple parameters such as supplier location. However, reasonable sourcing decisions should also consider changes in a supplier's technology, especially if environmentally competitive advantages are offered. To overcome this inherent issue of a single entity assessing the activities of a complex supply chain the most obvious improvement option is to have each involved stakeholder assess their own activities. These individual assessments are aggregated and passed on along the value chain in form of environmental footprints of materials, components, products, or services (= "Product Carbon Footprint Chaining"). To achieve consistency in methodology requires standardization on different levels, as well as a scalable enforcement of the defined rules. A digital PCF sharing approach is needed to enable the aggregation of supplier-specific values whilst monitoring the application of a standardized methodology that is applicable throughout value chains of different industries.

Who is working on standardization of product carbon footprint exchange?

Various communities and initiatives are currently defining PCF exchange and aggregation standards with data exchange protocols and formats that can be used across value chains:

WBCSD PACT - The World Business Council for Sustainable Development (WBCSD) is a global community of more than 200 leading sustainable companies working collectively to accelerate the transition to a sustainable world by making more sustainable businesses. The WBCSD Pathfinder Initiative, launched in March 2021, and the related WBCSD-hosted Partnership for Carbon Transparency (PACT)[5], is a collaborative initiative dedicated to enabling the widescale exchange of actual carbon emissions data in supply chains (Scope 3). Set up with an ecosystem approach, PACT brings together stakeholders from across value chains and industries, industry-focused initiatives, standard-setting organizations, leading technology

[3] R. García and F. Freire. "Carbon footprint of particleboard: a comparison between ISO/TS 14067, GHG Protocol, PAS 2050 and Climate Declaration." Journal of cleaner production 66 (2014): 199-209

[4] Bhatia, P. et al., 2011. Greenhouse Gas Protocol Product Life Cycle Accounting and Reporting Standard, WRI: World Resources Institute. United States of America.

[5] Pathfinder Network Technical specifications for Use Case 001: PCF Data Exchange: [20220614 For publication: Use Case 001 (carbon-transparency.com)]

companies, reporting bodies, and regulators to leverage synergies and combine expertise. The Pathfinder Network set up by PACT follows a solution-agnostic approach, focusing on creating interoperability to ensure that all organizations and value chains can connect and have access to the primary emissions data associated with their products. With its focus on aligning the business agenda with sustainability and as the convener of the GHG Protocol, WBCSD sees itself ideally positioned to lead this effort credibly and has detailed plans for the further development of the PACT network.

Catena-X is an open data ecosystem for the automotive industry. It connects suppliers and OEMs to end-to-end value chains. Catena-X is open, such that other industries and ecosystems can be integrated. Business applications to address use cases for digital, end-to-end supply chains with secure, sovereign, and standardized data exchange will be implemented.

Together for Sustainability (TfS)
Together for Sustainability is an initiative of the chemical industry with the aim of improving the industry's CSR standards. TfS provides a guideline for PCF calculation which is certified by TÜV Rheinland Energy to be consistent with the requirements of ISO 14067: 2018, WBCSD – Lifecycle Metrics for Chemical Products: 2014 and GHG Protocol Product Standard: 2011[6].

What are the technical working groups of ESTAINIUM?

ESTAINIUM's three technical working groups focus on different aspects of the association's vision. The first working group is selecting and developing the technical infrastructure which is needed for the exchange of product related environmental footprints. The second working group focuses on the alignment of different PCF standards and norms to achieve generally recognised data exchange formats along the value chain. And the third working group is developing guidelines to integrate high-quality carbon removal projects in accounting mechanisms and product lifecycle management. The working mode of the different groups is characterised by regular exchange and focus on identified challenges:

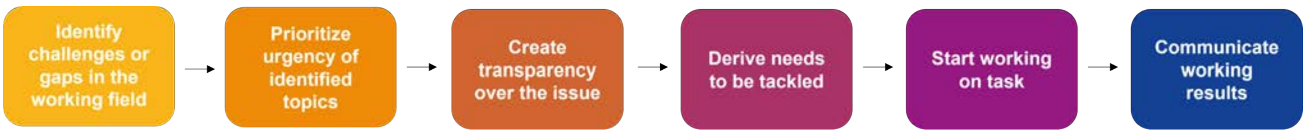

Figure 2 – Working Mode of ESTAINIUM's technical working groups.

In the following sections, each working group will give an insight into the main challenges and state of the working field, first results and an outlook on what will be addressed in the coming months.

[6] https://www.tfs-initiative.com/news/tfs-product-carbon-footprint-guideline-is-now-tuv-certified

WG 1 – Technology and infrastructure

Besides interoperability, data sovereignty and confidentiality requirements must be identified and implemented. This is the aim of the first working group, which is selecting and developing the technical infrastructure for the exchange of product carbon footprints and other ESG (environmental, social and governance) data. Currently, the focus of the association's work is on the impact category climate change (i.e. PCF reflecting global warming potential of greenhouse gases characterized by kg CO_2e emissions per declared unit), but an expansion in the future is not excluded. The members of the association will co-design this technology stack, which is an open-source solution and allows every software provider to connect their solution to the ESTAINIUM network. The technology is based on the approach of self-sovereign identities of IDunion. The first working group addresses the following targets:

- Identify requirements (e.g., data sovereignty, confidentiality) on technology and infrastructure ensuring acceptance by the industry,
- Select base infrastructure and develop necessary extensions when using the infrastructure for PCF/ESG data sharing,
- Develop and publish architecture, building blocks, and joint standards for exchanging PCF and ESG data, and
- Identify and/or setup an organization for operating the sharing infrastructure.

What are the main technical requirements for a PCF sharing infrastructure?

This section lists the requirements of technology and infrastructure for PCF sharing in supply chains. Some of these requirements may also apply to product-related information of ESG data.

Functional Requirements: The key functional requirements of a PCF sharing infrastructure that goes beyond today's industry average based life cycle assessment practice, as described above, would include:

- **Product definition**: Companies can add and manage products and product families. Products are comprised of components and/or materials. Components and materials are sourced from suppliers. The bill of material version reflects a product's supply chain.
- **Supplier onboarding**: Companies can engage their suppliers in an efficient digital way of PCF sharing.
- **PCF requesting, receiving, and sending**: Companies can request PCF data from their suppliers digitally. The PCF requests are sent out per component. Companies receive requests from their customers to share their PCF data for a specific product. Companies reply to a request by sending the PCF data for a given product.
- **PCF aggregation**: Based on the bill of material and a company's emissions, the PCF of a product can be aggregated throughout multiple tiers in the supply chain.
- **Compensation**: The sharing approach should accommodate for trustworthy aggregation of PCF values and emission compensation values that may be relevant at each upstream supply tier.

Openness: The platform and the relevant standards should be open, regarding participation and software development. PCF sharing requires the cooperation of many companies across diverse industries. Only an open platform that many parties can easily use enables the creation of a large community with the ability to change today's limited practice. Every organization should be able to participate in the sharing solution in their specific role. Clear and understandable entry criteria should be defined, which in principle, do not exclude any company and can be fulfilled by everyone. Furthermore, to ensure constant improvement and adaptation to user requirements, adherence to principles of open-source software development should be essential to ESTAINIUM's work.

Data transparency: The PCF data, origins, and flows should be understandable to the relevant parties. It is crucial that this is a bidirectional process in which customers receive information about the product and suppliers are made aware of how that information is used. Furthermore, it should not be possible for the data to be forwarded to other participants without the permission of the data provider. In this way, trusting relationships along the supply chain are created.

Trustworthiness: PCF data sent from a supplier to a customer should be in a verifiable format such that the customer receiving the data can verify the correctness and quality of the data based on trust assumptions and standard digital signature schemes.

Confidentiality: Only parties that are directly involved with a product should have access to its PCF data. Similarly, internal processes and proprietary information may only be shared voluntarily, as unnecessary disclosure obligations will divert companies from a sharing platform. Information about logistics, suppliers and bills-of-material must be kept confidential.

Standards: The key functionality of sharing PCF data across supply chain participants should be based on mature non-proprietary, industry-accepted standards and open-source software. Standards on protocols and data semantics for PCF exchange can lead to significant cost savings compared to proprietary PCF-sharing approaches.

Industry Neutrality: Standards, data formats, and processes of the sharing approach should be industry neutral. ESTAINIUM aims to achieve a transformative change across complex, interconnected value chains, which often feature many industries. Creating a universal infrastructure that can accommodate a diverse range of companies is essential to enable data aggregation across multiple sectors.

Large and Small Enterprises: The integration of the platform and participation in the sharing community should be feasible for large and small enterprises alike. Holistic PCF aggregation requires the involvement of all companies along the value chain, which usually includes many small companies that lack the resources for exhaustive software projects. The approach must be designed for simple entry of companies of all sizes.

Data quality: The ESTAINIUM foundation is committed to ensuring a high level of data quality. As efforts to improve PCF in all sectors depend on data about the status quo, ensuring its accuracy and completeness is vital. Additionally, the timely and consistent provision of necessary data is at the core of the development process. Data quality also includes the auditing of the data acquisition process.

Efficiency: The sharing system itself must have minimal emissions during its operation.

PCF = Product Carbon Footprint

ESG = Environmental, Social and Governance

LCA = Lifecycle Assessment

PCR = Product Category Rule

PSR = Product Specific Rules

EPD = Environmental Product Declaration

GHG = Greenhouse Gas

What technologies exist for PCF sharing?

Online Database: Product-related information can be shared most simply through an online database. Such an approach is used by the International Material Data System (IMDS) to store information on the materials that are used to manufacture motor vehicles. This approach is typically centrally managed by a single organization.

Data Connector: In a step towards a decentralized data space, digital connectors are used by different companies to provide and consume data in a controlled manner. For instance, Catena-X uses the Eclipse Data Space Connector (EDC) to implement self-sovereign and cross-organizational data exchange. The EDC implements a framework agreement for sovereign, cross-organizational data exchange, which is based on the International Data Spaces Standard (IDS) and relevant principles in connection with GAIA-X. The connector is designed to be extensible to support alternative protocols and to be integrated into different digital ecosystems.

Verifiable Credentials: Verifiable Credentials go even further to enable a decentralized sharing approach. We know credentials in our daily lives. A driver's license is used to assert that we can operate a motor vehicle, a university degree can be used to affirm our level of education, and a passport enables us to travel between countries. A verifiable credential can represent the same information as a physical credential. The addition of technologies, such as digital signatures, makes verifiable credentials more tamper-evident and trustworthy than their physical counterparts.

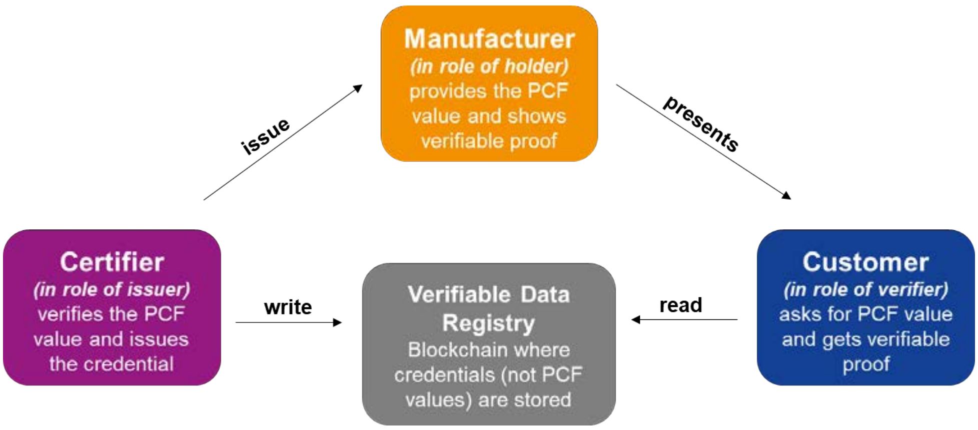

Figure 3 – Verifiable Credential Approach in context of PCF-sharing in Manufacturing Industry

There are three different parties involved in the verifiable credential data model, which is presented by W3C[7]. These are the issuer, holder, and verifier. A holder is a role an entity might perform by possessing one or more verifiable credentials and generating verifiable presentations from them. An

[7] World Wide Web Consortium (W3C). Verifiable Credentials Data Model 1.0. 2019. https://www.w3.org/TR/vc-data-model/

issuer is a role an entity performs by asserting claims about one or more subjects, creating a verifiable credential from these claims, and transmitting the verifiable credential to a holder.

Trustworthy supply chain exchange (TSX) is a method for the exchange of certified product-level information (e.g., CO_2 emissions or environmental, social and governance properties) in supply chains based on verifiable credentials. TSX addresses requirements on transparency, confidentiality and data control when sharing information across supply chain stakeholders.

Certifiers are already key in anchoring trust in complex supply chains. In the application, TSX for product carbon footprints, a manufacturer of components and products has a selected certifier who takes on the role of issuer of product carbon footprint (PCF) certificates in the form of digitally signed verifiable credentials. Based on the knowledge of the manufacturer's production process and the carbon emission measurement method, a certifier can issue a PCF certificate to a manufacturer. Thus, the manufacturer is the holder of the PCF certificate. A manufacturer can now derive cryptographic evidence based on attributes from one or more PCF certificates and present it to a customer. The customer, in the role of verifier, can use the public digital keys of the certifier to check the correctness of the evidence presented.

Important to highlight is that there are two "verifying" processes:

- verification of PCF value, meaning auditing the calculation procedure and result of a PCF value, executed by an independent third party (="certifier").
- digital verification of a credential, meaning to check the shared PCF against the cryptographic keys on the blockchain.

The three roles of issuer, holder and verifier of PCF certificates are applied in several stages in the TSX approach: firstly, a manufacturer is in the role of the holder of certificates relating to its own products and secondly a manufacturer is also in the role of the verifier of the evidence presented by its suppliers. The multi-stage application of PCF certificates allows a customer to verify the aggregated product carbon footprint in a trustworthy manner regarding the complete composition of parts and materials for which certifiers issued PCF certificates in previous stages of the supply chain. Confidential details about the identity of the suppliers, components and materials are protected with this approach and cannot be viewed by the verifying customer. The manufacturer also controls carbon emission data and decides when and with which business partner it should be shared.

Are existing technologies for PCF sharing fulfilling the requirements?

This section discusses how initiatives use the identified technologies and how they address the requirements described earlier in this paper.

WBCSD PACT provide openness in various degrees and based on respective governance. Also, data transparency is addressed by WBCSD PACT as it is by data connectors and verifiable credentials.

However, online databases provide limited transparency in some cases because they were not designed necessarily on Web2 principles of bidirectional data generation. Trustworthiness and confidentiality, in combination with data transparency, is not supported by systems based on online databases. WBCSD PACT is also not focused on trustworthiness and confidentiality because its focus is on accounting methods and frameworks. Catena-X and other systems based on data connectors are currently not technically able to share third party certificates which can automatically verify received PCF values. Verifiable credentials, however, do give a foundation to address both non-functional requirements, data transparency and confidentiality. Trusted Supply Chain Exchange (TSX) shows how verifiable credentials can be used in a chained manner.

The objective to set a standard for data exchange in supply chains is shared by all initiatives. The sharing technologies are all related to standards from different standardization bodies (ISO, GHG Protocol, W3C). The aim of addressing industry neutrality for large and small companies is expressed by all initiatives and technologies. Data quality is a particular focus in the WBCSD PACT initiative as it is a concern addressed by all identified technologies.

The final requirement of efficiency is essential for all initiatives and technologies. However, the PCF of the sharing system or technology is difficult to estimate.

Activities of the Working Group to address the identified challenges:

- Define objectives and requirements for data sharing in supply chains.
- Research existing technologies and infrastructures for PCF sharing and compensation.
- Identify limitations of existing sharing technologies and infrastructures with respect to the defined requirements.
- Recommend an industry-agnostic technology stack for PCF sharing and compensation.
- Perform a pilot on interoperability with various PCF management applications over an infrastructure based on the recommended technology stack.
- Develop extension to the ESTAINIUM technology stack.

"Call for Action"
Join the interoperability pilot with your PCF management application and influence the emerging de-facto industry standard for data sharing in supply chains.

WG 2 – Standards and Norms Compatibility

One of the most critical prerequisites for fulfilling the vision of a primary data-driven decarbonization of the supply chain is the existence of widely recognised data exchange formats. The second ESTAINIUM working group focuses on promoting a harmonized landscape of standards and methodologies in the field of PCF to foster a lively and trusted data exchange across the industry. Major activities are the alignment of the required data models, the identification of suitable assurance schemes allowing a scaled-up verification practice, and the development of guidance and best practices for members approaching PCF topics. The members are working together with leading initiatives in Life Cycle Assessment and Product Carbon Footprinting. The goal is to establish consistent methodologies to ensure interoperability and to enable meaningful and aligned integration of new areas like the carbon sink domain.

What are the challenges in calculating and exchanging PCFs?

In current practice environmental impacts such as global warming potential expressed by the PCF are derived by LCA practitioners modelling the upstream value chain based on secondary data, thereby not including primary data from suppliers. This brings upon following challenge. Whilst a single entity assessment of the value chain has a lack in supplier specific data, this approach can guaranty a high consistency in the methodology in its assessment. In contrast, a distributed assessment approach (in the following referred to as Product Carbon Footprint Chaining) might provide the possibility to utilize the most specific data possible, however, a sufficient consistency in methodology applied by all stakeholder seems less likely. To achieve high consistency in methodology requires standardization on different levels, as well as a scalable enforcement of the defined rules. Standardization of PCF calculation and reporting and many aspects of related processes are the most relevant preconditions to derive meaningful results when reallocating assessment responsibility from a single person to a network of actors along the value chain. The following paragraphs highlight key elements that need development and alignment for supporting product carbon footprint chaining, as judged by the perspective of life cycle assessment practitioners within the ESTAINIUM community.

PCF-Chaining
Distributed assessment approach for aggregating PCFs with supplier-specific data along the supply chain

Methodology alignment

The leading LCA standards ISO 14040/44 and PCF standard ISO14067 provide high-level guidance and rules for how to approach an assessment. Transparent documentation of methodological assumptions and data collection steps is required. However, practitioners are left with many subjective choices to make. Further guidance documents building on the ISO standards provide more detailed and narrow rulesets. Such documents exist on multiple levels, which can be grouped into:

- cross-sectorial rules (e.g. WBCSD Pathfinder or EU Product environmental footprint),
- sectorial rules/ product category rules (e.g. Catena-X for the automotive sector, DIN EN IEC 63366 as PCR for electronic products or IEC TS 63058 for switchgear and control gear).

Due to increasing demand for environmental product declarations (EPDs) in the market, the number of product category and product specific rules also increases. Individual EPD programs often publish such rules which, however, can differ in methodological requirements and terminology. While the comparability of assessments following the same narrow ruleset is ensured, a methodological mismatch compared to other rulesets becomes more likely. This may cause substantial inconsistencies, once PCFs are chained along the supply chain. Although cross-sectoral standards are generally applicable to many products, the lack of specific rules forces practitioners to make more subjective choices. Again, a lack of consistency between different LCA studies might be the consequence.

PCF exchange data model

The exchange of product-related assessment results often needs to be complemented by descriptive meta data for the target audience. Such meta-data form a data model comprising attributes describing the product, the applied assessment methodology, data collection, quality indications, and verification statements. Although the LCA standards from the ISO 14000 series request a transparent description in the assessment report, a practitioner can often choose which attributes to disclose when exchanging data with other stakeholders. For transparency, a minimum of insight into selected methods and assessment scope is necessary to compare any received PCFs. Hence, a standardized data format is essential.

It can be observed that some of the major PCF initiatives keep updating their standard documents in frequent intervals, e.g. almost on an annual basis, which is reflecting the iterative process that requires consensus of members on the one hand, and actual practitioner feedback on the other hand. Updated document versions may include changes in required attributes or even calculation logic. Solution providers such as PCF sharing platforms or secondary data bases need to keep up with the update cycles. Inconsistencies among different versions of the applied data models can be a consequence. Alignment efforts between the initiatives potentially also increase after each update introducing new discussion points.

Enforcement via standardization

The overall need for consistency in methodology requires standardized rulesets that are both applicable for a wide range of products and sufficiently narrow to increase comparability. It can be argued that the choice of methodology can have a significant impact on how the environmental impacts are calculated and attributed between different product systems. Assuming an equal set of narrow rules for all supply chain participants calculating environmental footprints, some sectors could be benefited while other sectors would be seeing a disadvantage in terms of which impacts are attributed to their product system. Standardization aiming at achieving consistent methodologies across exchanged PCFs faces the challenge of tradeoffs between high comparability and the perception of fair rules.

Mainstreaming LCA knowledge

In general, PCF calculation follows LCA principles that require a certain level of expertise. LCA practitioners usually receive training in how to conduct LCA studies according to the relevant standards. Non-experts without such training often lack essential capabilities to approach PCF calculation and interpretation, such as method selection, setting of system boundaries, definition of allocation factors, end-of-life treatment approach, emission factor selection, calculation of specific GHG emission categories or interpretation of input and output data. In short: the practice of conducting and interpreting LCA is not yet mainstreamed enough to sufficiently accelerate PCF sharing in the industry.

However, multiple pathways are currently explored by the LCA community to better equip non-experts with means to derive a PCF value:

- Consultancy services (e.g. offering case by case PCF calculation)
- Full sustainability services (for company and product level carbon footprinting based on own activity data and secondary or primary emission factors)
- Data bases with ready to use emission factors for specific sectors and industries: e.g. chemicals, mining, food and beverages, transportation
- Advice on how to use existing data bases designed for corporate carbon footprint calculation
- Calculation-engines with low entry-hurdle data input for rough estimations
- Guidelines including step-by-step procedures for rough estimation of own activity data

A lack of knowledge about which standards and guideline documents are relevant for the use case of a specific non-expert is considered a main entry barrier into carbon footprinting. An easy access to an overview and guide for navigating the standards landscape would be valuable for accelerating the adoption of a PCF calculation practice. In addition, the sharing of best practices among peers is considered to be a valuable source of information for beginners in the field. Due to confidentiality reasons the access to such best practices is often limited or exclusive to small groups.

Judgement of quality and specificity

An evaluation of uncertainty and representativeness of data and methodological assumptions is required to ensure overall quality of an assessment. Such evaluation is an integral part of the interpretation phase of every life cycle assessment study. The current literature provides many examples for both quantitative as well as qualitative approaches.

Quantitative approaches, such as error margins derived by Monte Carlo analysis, typically require detailed data and preparation work. The advantage can be robust indications for decision support paired with insights into impacts of different scenario choices.

Qualitative approaches are often very subjective with high-level evaluation of uncertainty and representativeness levels. A typical example for evaluating the representativeness of various data inputs is a Pedigree-Matrix. Different categories (e.g. geography, time, technology, completeness) are qualitatively rated by discrete levels, such as poor, good, or very good. The PCF initiatives strive for an exchange of high quality PCFs and therefore require the reporting of representativeness scores as meta-data. An alignment across all standards on how to approach representativeness assessment has not been fully achieved so far.

As quality is by nature a value-based attribute, specific characteristics can be considered of high value to practitioners. The primary data share indicator is an indicator of supply chain specificity and can be considered to be of increasing importance, especially with regards to PCF exchange across the supply chain. However, as most LCA studies still heavily rely on secondary data from data bases, the primary data share has not been demonstrated in many LCA studies to judge its significance. The implementation of primary data share calculation requires the addition of an extra parameter running besides emission factors and activity data. Nevertheless, the major PCF standardization initiatives are promoting the use of this indicator. The definition provided by each initiative vary in some points which may lead to inconsistencies or even preferred selection of one standard over the other.

Primary data share
Index for propagating the share of primary data (activities, emission factors) contained in aggregated PCFs

Assurance

The generation of trust is of major importance when companies make claims about environmental impacts of their products. One key element for anchoring trust is a transparent description of assumptions and methodology applied in the form of meta-data complementing a PCF value. Another trust anchor can be the verification of the methods and results by a third party. There can be multiple approaches towards verification results: e.g. benchmarking against accepted values, peer-review, verification of calculation method only, conventional case-by-case verification of certification bodies.

The case-by-case verification by accepted 3rd parties currently has the highest trust potential. Nevertheless, scalability of this approach is limited, as capacity of qualified personnel is considered a major bottleneck. Other approaches with higher scalability potential need to fill this gap to reach an acceptable level of trust and assurance. There is a clear need for a streamlined verification scheme that is accepted by the majority of stakeholders and responsible initiatives. Standardization of both the levels of verification as well as the verification process itself is required. Once a standard procedure for verification is agreed upon, also the receivers of verified information need to be educated on how to read and interpret verification statements.

Assurance has been assigned a major topic among all leading PCF initiatives. The WBCSD pathfinder framework introduces a high-level assurance scheme to highlight the importance for generating trust. Specific emphasize is put on varying requirements for practitioners in the short- and long-term future with many parallels to corporate carbon footprinting standards. In parallel, also Catena-X engages in the topic of verification with specific work group activities. The aim is to set the ground for a verification standard by defining verification practices and resulting levels of authenticity.

What is ESTAINIUM doing to address these challenges?

The alignment of PCF methodologies published by the PCF standardization initiatives WBCSD Pathfinder, Together for Sustainability and Catena-X is a major activity of the working group. The following approach is taken: In a first step members create transparency about the current state, commonalities, and incompatibilities. Secondly, proposals towards alignment of specific methodological aspects or data model attributes are internally discuss and prepare. Next, ESTAINIUM facilitates the alignment process between the major initiatives or engages in existing formats to actively promote and defend these proposals in joint discussions. At the current stage, there are no intentions of a standalone ESTAINIUM standard to be published alongside. In contrast, ESTAINIUM acts as a neutral discussion partner aiming at reaching consensus among the initiatives that define and publish PCF standard documents. The main advantage of ESTAINIUM and its working groups is the cross-sectoral perspective and the expertise developed in the field of PCF exchange mechanisms for monitoring and communicating methodological requirements arising among practitioners engaging in PCF exchange.

The collection and sharing of the combined LCA knowhow and PCF accounting experiences from ESTAINIUM member institutions is a declared goal of working group 2. For this purpose, a digital knowledge hub is currently being created that will be accessible to all members. The knowledge hub will feature various items to help equip members with necessary tools and shortcuts to start and manage their PCF journey, including the following:

- A knowledge graph will provide an overview of relevant LCA and carbon footprinting standards, both on product and corporate level. Additionally, the user can further filter documents regarding covered sectors or products, version, publishing program, existing interdependencies with other standards, and others. The aim is to quickly enable members to pre-select the most relevant documents for their individual assessment scenario.
- A best practices collection of members active in the field of environmental impact assessment is being provided to foster exchange among members and lower entry hurdles by non-experts. This collection will be accompanied by a learning-platform with access to tools, literature, and teaching material.
- A glossary of frequently used terminology will be provided to ensure a common understanding withing ESTAINIUM. At a later stage a wiki-type knowledge base will be added to increase the accessibility of generated content

Another key activity aims at increasing transparency in the field of current PCF verification practices. Members with prior experience collect common practices and create high-level guidance for beginners. This covers an analysis of verification requirements defined by general standards and commercial programs managing environmental product declarations (EPD). Special attention is given to the scalability of existing and potential new verification levels. This encompasses a comparison of benefits and limitations of the various practices, such as conventional case-by-case verification vs. verification of the underlying calculation method only. To increase the reach and increase alignment, members actively contribute to parallel verification working groups of other initiatives, such as Catena-X.

The primary data share gains importance as quality indicator among the PCF standardization initiatives. Working group 2 identified challenges arising from varying definitions of the indicator, which could impact a consistent PCF exchange practice. As active contribution, the working group kicked-off a scientific investigation on the implication of the primary data share as quality indicator. A research institute is tasked to provide an independent analysis of the use of primary data share in various use cases. In a next step, the members will discuss whether additional alignment of the definitions is needed to ensure that the intended effect of a primary data share is achieved in PCF data exchange.

Activities of the Working Group to address the identified challenges:

- Data model alignment between PCF initiatives
- Creation of ESTAINIUM knowledge hub:
    - standards knowledge graph with standards overview,
    - best practices collection for PCF calculation,
    - PCF glossary and wiki,
    - training material
- Streamlining of PCF assurance/verification practices
- Investigation of primary data share as quality indicator in PCF chaining

“Call for Action”:
Join one of our expert teams and contribute your LCA knowhow to help develop and promote the ESTAINIUM vision of an aligned cross-industry PCF chaining landscape.

WG 3 – Carbon Capture, Use, Storage & Compensation

Carbon sequestration has recently attracted scientists and industry interest with expertise across a range of nature-based and engineered technologies to look at potential barriers to uptake, as well as co-benefits. Offsetting unavoidable emissions by investing in carbon removal projects is part of many transformation strategies. This leads to a very dynamic development in voluntary carbon markets. The third working group aims to create transparency in this topic area and develop technical solutions for integrating trust-worthy projects into value-creation networks. This working group highlights the opportunities to capture and store atmospheric carbon dioxide as part of a products life cycle and identifies carbon removal technologies to create reliable and valuable products that lower the net costs of reducing emissions or removing carbon dioxide from the atmosphere. Therefore, the working group reviews the latest developments in the field to define criteria for selecting carbon removals, accounting methodologies and offsetting mechanisms. The main challenge is to understand the linkage between carbon emissions, carbon removal technologies and offsetting within a holistic market instrument that embraces highest standards and sustainability approaches. The working group enhances existing digital supply chain ecosystems interfaces with the scope of providing templates for a grid of carbon sinks offering different services. Summarized, this working group addresses the following targets:

Carbon Credit[8]
A certified and transferable instrument representing one tonne of CO_2 equivalent emissions that were reduced, avoided or removed from an **offset project**.

Offsetting[8]
The process of retiring carbon credits to compensate the equivalent volume of emissions.

Carbon Sequestration[9]
The uptake of CO_2 and storage of carbon in biological sinks.

Carbon Dioxide Removal (CDR)[10]
Human activities capturing CO_2 from the atmosphere and storing it durably in geological, land or ocean reservoirs, or in products.

Carbon Sink[11]
A sink is any process, activity or mechanism that removes a greenhouse gas from the atmosphere.

- Identify carbon dioxide removal technologies as part of the product life cycle.
- Define criteria for selection and comparison of carbon dioxide removal projects.
- Define evaluation and certification processes to ensure best practices in offsetting.
- Develop templates for tracking carbon along a product's lifecycle.
- Discuss accounting mechanisms for reporting PCFs next to carbon dioxide removals.
- Examination of the regulatory framework and development of recommendations for action

What are the main challenges in the field of carbon dioxide removals?

There are several challenges that need to be addressed so that carbon dioxide removals can make the necessary contribution to combating climate change:

[8] adapted from EY, "Essential, expensive and evolving: The outlook for carbon credits and offsets" (2022)
[9] Greenhouse Gas Protocol
[10] The State of Carbon Dioxide Removal doi:10.17605/OSF.IO/W3B4Z (2023)
[11] EU Regulation 2018/841 (2018)

Environmental challenges
Carbon removals in natural ecosystems have decreased over recent years and no significant industrial carbon removals are currently taking place. Some carbon removal projects are not actually delivering the removals as planned and projects can have undesirable side effects. The assessment of possible impacts on local environments is required to prevent possible loss of biodiversity. Furthermore, the risk that carbon is released back into the atmosphere (leakage) must be quantified and addressed.

Legal and accounting challenges
There are difficulties in assessing and comparing the quality of carbon removals. Correctly quantifying carbon removals (MRV) is difficult, especially for natural carbon sinks. The duration of carbon storage is not equal for different projects, short-term storage (most products) is not currently considered as carbon removals. Harmonization of certification methodologies and procedures is needed since there are questions regarding preventing double counting[12] in GHG audits. Many stakeholders do not trust carbon removal certificates because certification schemes may not follow transparent and robust rules.

Socio-economic challenges
Many providers of carbon removals face barriers in accessing finance. The markets for carbon offsets and sustainable financial instruments are complex and evolving dynamically, as are the regulations in this area. Encompassing broader sustainability impacts is an extensive task and requires interaction with communities and experts. Furthermore, carbon removal projects must be monitored over the long term to ensure that CO_2 remains sequestered.

What kind of carbon dioxide removals are existing?

Depending on the duration of carbon sequestration, it is possible to find differences in permanence, from the most permanent sinks, like geological sequestration or ocean burial to low permanence ones, such as herbaceous vegetation or bio-manufactured building materials. Depending on the nature of the component, we can find different types of natural sinks, such as forests, soil or oceans. But there are also artificial sinks where, instead of being part of nature-based carbon cycle processes, a series of human-driven processes from carbon capture or carbon-lag processes promote carbon retention. Among CDR activities, it is possible to differentiate between the following:

Natural-based solutions
- Land Use, Land-Use Change and Forestry-related projects (LULUCF)
- (Including Afforestation, Reforestation)
- Blue Carbon (Mangroves, Seagrass)
- Macro-algae (Seaweed)
- Soil Carbon Sequestration

Technological solutions
- Bioenergy with carbon capture and storage (BECCS)

[12] https://www.offsetguide.org/high-quality-offsets/exclusive-claim-to-ghg-reductions/

- Direct air capture carbon storage (DACCS)
- Carbon Capture and Manufacture (CCM) – ex: (Forest Products, Algae products)
- Enhanced Weathering (EW)
- Biochar

Technologies to capture CO_2 at point sources such as fossil power plants or industrial processes, which are usually listed under the term CCS (Carbon Capture and Storage), are not included because the source of CO_2 is not the atmosphere. These technologies are therefore assigned to the category "Carbon Reduction". A study carried out for the European Commission evaluated the potential of several carbon removal solutions and assessed their suitability for deployment within Europe. In the study, solutions are grouped into three families based on where the removed carbon is stored:

Permanent storage solutions have stored atmospheric or biogenic carbon for several centuries, either in geological reservoirs (see BECCS, DACCS) or in other media.

Carbon farming solutions enhance carbon sequestration in soils or in living biomass in synergy with other sustainability objectives such as biodiversity: (see Afforestation, Reforestation, Blue Carbon, soil carbon sequestration, etc.)

Carbon storage in products stores atmospheric or biogenic carbon in materials that are used to make long-lasting circular products. (e.g. wooden buildings)

With this initiative, the EU wants to develop a quality label for carbon removal projects and refers to typical quality criteria as they are also demanded by other players in the market (quantification, additionality and baselines, long term storage and sustainability). Other examples for existing quality schemes of carbon offsets are the ICROA (International Carbon Reduction and Offset Alliance) scheme, which states the following requirements for high-quality carbon credits: real, measurable, permanent, additional, independently verified, and unique; the "Core Carbon Principles" of ICVCM or the scores for carbon of CCQI. ICROA also endorsed independent standards for projects on the voluntary carbon market. Currently, for example, Gold Standard, Verified Carbon Standard, Plan Vivo and Puro.earth are standards accepted by ICROA.

How to buy carbon dioxide removals?

ESTAINIUM looks at all these initiatives and builds on them by developing quality criteria for linking carbon footprint management and accounting mechanisms with investment in carbon removal projects. A set of quality criteria were identified for the development of marketplaces for offsetting product-related emissions:

Transparency: the prospective customer of a product from a marketplace needs to get an overview of the different mitigation methods, suppliers and products to achieve the desired carbon compensation; and ultimately increase the democratization of CO_2 relevant decision-making processes.

Innovative Processes: in the future, both the demand side (emissions) and the supply side (removals) could participate in a holistic market. This market could support newly developed carbon-binding production processes and materials that can be matched to the needs and offers of market participants.

Buy-to-Retire: transactions between sellers and buyers of carbon credits must result in the respective credits exchanged being retired to ensure climate impact.

Holistic Accounting: as soon as tangible products are shipped from the sink to the compensator, the PCF of the transport component must be deducted automatically.

Compliance: The marketplace must be designed so that a potential double usage of carbon credits is technically impossible. Finally, a marketplace must check and make transparent to what extent the projects offered have an impact on the SDGs.

The following points on the possible further development of the existing legal framework can serve as a basis for a more in-depth discussion with legislators:

- The legal framework is crucial to provide certainty for companies, shareholders and investors. Against this background the legal framework must create the greatest possible investment security for companies, investors and financiers.
- ESTAINIUM believes that sink performance should be officially recognized by the legislator. Different sorts of sinks must be made comparable, respective criteria need to be developed. This needs to be anchored in the legal framework.
- Regulations on sink provider requirements should be developed: There should be an open discussion on whether suppliers of CO_2 sinks themselves must be climate neutral before they sell or trade CO_2 sinks.
- There should be a discussion of how carbon emissions and carbon removal could be linked in legislation. Separate offsets reporting is necessary, but carbon pricing regulation instruments should consider voluntary activities to remove CO_2.
- Criteria are needed to distinguish avoidable from non-avoidable emissions. Such criteria need to be transparent and could be based on legally binding rules.
- There should be a discussion how carbon emissions and carbon removal could be linked in legislation. Separate reporting of offsets is necessary, but carbon pricing regulation instruments should consider voluntary activities to remove CO_2.

In the coming months, ESTAINIUM will work on an extension of these lists with the target to specify how the connection of emissions and sinks can be combined with net zero strategies of countries and corporates. Currently, carbon removals account for only a small share of the voluntary or mandatory carbon markets. Prices for high-quality removal projects are very high, as many projects are still in the development stage.

*See Oxford Offsetting Principles, picture adapted from carbonware.substack.com

Figure 4 - Overview of the voluntary carbon market

Aiming to develop a quality index for carbon removals to achieve more transparency and easy comparability of different carbon removal types, we first compared existing estimates for costs and quantitative potentials. You can see the interactive graph and more information on different types of carbon removals on the association's website.

Look at the interactive graph on the ESTAINIUM website.

Every technology is linked to different natural resources, which impacts the decision for the best solution, depending on local capabilities. You can see an overview of the interaction of varying carbon removals with diverse natural resources in the following table:

	CDR Methods	Forest Resources	Water Resources	Land Resources	Renewable Energy Resources	Rare Minerals	Geological Reservoirs	Clean Environment
Permanent Storage	BECCS	-		-	+		-	
	DACCS		o	o	-	-	-	
	Enhanced Rock Weathering		-	-	o	o		-
	Ocean alkalinisation			o		o		o
	Ocean Fertilisation							-
Carbon Farming	Afforestation/Reforestation	+	+	-				+
	Improved Forest Management	o						+
	Agroforestry			o	+			+
	Blue Carbon	+	+					+
	Biochar	-		+	o			
	Petland and Wetland	o		-				+
	Soil carbon sequestration			+				+
Carbon storage in products	Biomass in buildings	-		-	o			o
	Algae products		o					+
	Forestry products	-			o			o

Legend	
+	Synergies/Benefits
-	Trade-offs/challenges
o	Both synergies and trade-offs
	Blanks represent no assesssment / no impact

Figure 5 – Interaction of Carbon Dioxide Removals and natural Ressources

ESTAINIUMs Working Group 3 will discuss further indicators for comparing the quality and potential limiting factors of different carbon removal types, focusing on impact assessment related to the UN sustainability goals. Furthermore, questions around the use of carbon-based products like bioplastics as carbon sinks will be addressed.

Activities of the Working Group to address the identified challenges:

- To create transparency and enhance comparability, we are working on a quality index for carbon removals – you can see first results in an interactive graph on the ESTAINIUM website.
- To test the idea and technical requirement of linking emissions and sinks, we are conducting different technical pilot projects. You can see an overview in our mission statement paper.
- To generally design quality criteria for offsetting processes, we incorporate best practices.
- We enter discussion with politics to support a regulatory framework which incentives high-quality projects.

"Call for Action":

Contribute to the discussions on a quality index for carbon removals and best practice guidelines for integrating offsetting into product lifecycle management.

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